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REVIEW ARTICLE

Craniofacial Resection for Malignant Neoplasms of the Skull Base: An Overview

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Advances in combined transcranial and transfacial (craniofacial) approaches for malignant tumors involving the anterior skull base have demonstrated improved survival. The technique allows adequate assessment of the intracranial extent of the tumor through an appropriate craniotomy. Vital structures, such as the dura, brain, and blood vessels, can be protected or resected and reconstructed safely. An en bloc excision can be accomplished. Dural defects and/or tears are satisfactorily repaired under direct vision, ensuring a watertight closure. Finally, adequate closure of the soft tissue defect is obtained, thus segregating the cranial cavity from the potentially infected nasal cavity and the nasopharynx with a resultant decrease in morbidity. Operative mortality is low, although complication rates are high. The technique is safe and continues to be improved to reduce morbidity. To evaluate the true impact of this surgical procedure on improvement in survival as well as quality of life, a multiinstitutional registry with uniform indications is indicated. With increasing experience and well-defined indications, improvement in survival (from 50% to 60%) and reduction in morbidity (from 30% to 40%) can be demonstrated through multiinstitutional, cooperative efforts.

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KEY WORDS: craniofacial resection; skull base; malignancy

INTRODUCTION

The skull base is the complex boundary between extracranial and intracranial tissues through which vital vessels and nerves pass. Historically, the high morbidity of skull base surgery and the inability to achieve an en bloc resection has limited the usefulness and efficacy of skull base resections for malignant tumors [1–5]. Advances in surgical access to the skull base and in reconstruction techniques have enabled surgeons to safely resect malignant skull base tumors that would have been considered inoperable in the past. Here, we present a summary of the recent literature describing the applications, limitations, results, and complications of craniofacial resection for malignant skull base tumors. Skull base malignancies originate from the bone, dura, blood vessels, nerves, or the epithelial and glandular tissues of the sinonasal tract, face, and ear. These cancers invade the skull base from their sites of origin in the nasal cavity, paranasal sinuses, orbit, ear canal, skin, salivary glands, and nasopharynx or by distant metastases from cancer of the lung, breast, prostate, kidney, or other site. Although malignant lesions of the skull base are a histologically diverse group, the results of their resection are commonly reported together, making interpretation of survival and control statistics difficult.

Skull base surgeons of the middle part of this century were hampered by poor imaging and staging and the lack of advanced reconstructive techniques, which allowed

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frequent cerebral spinal fluid fistulae and meningitis [1]. Cushing [6] and Dandy [7] described the transcranial, transfacial approach for orbital tumors in 1941. Other pioneering reports came from Rae and McLean [8] in 1943, Smith et al. [9] in 1954, and Malecki [10] in 1959. However, in1963 Ketcham et al. [11] were the first to systematically describe the combined transcranial and transfacial approach to tumors of the paranasal sinuses involving the anterior skull base, showing an improved survival in these patients. This report was followed by many descriptions of surgical approaches to the cranial base [12–25]. The development of computerized tomography (CT) in the 1970s and magnetic resonance imaging (MRI) in the 1980s revolutionized the surgeon's ability to assess tumor extent, thus facilitating a precise and safe surgical approach. The availability of rigid fixation devices to stabilize the facial skeleton in its normal position with a low risk of infection and non-union paved the way for the development of exposure osteotomies and facial disassembly procedures for improved intracranial and extracranial exposure [26–28]. Still, the first reports of these techniques described significant rates of infection and cerebrospinal fluid (CSF) leaks [18,19,28]. This was mainly due to the inability to obliterate the resulting dead space and the lack of an effective seal and separation between the intracranial space and the potentially contaminated sinuses. It was the use of local pericranial, galeal-pericranial, and eventually vascularized free tissue transfer, which lead to a decrease in CSF leakage and meningitis, the principal causes of morbidity and mortality from skull base operations. Today, skull base surgery teams depend on head and neck surgeons, neurosurgeons, microvascular plastic surgeons, maxillofacial prosthodontists, interventional and neuroradiologists, radiation oncologists, neuroanesthesiologists, intensivists, and rehabilitation specialists to successfully remove skull base malignancies and then reconstruct and rehabilitate patients. These cooperative efforts have improved survival, morbidity, and mortality of skull base surgery [12–20,22–24,29–52].

SURGICAL ANATOMY

The skull base is a complex arrangement of bones and spaces connected by fissures and foraminae which transmit important vessels and nerves. These fissures and foraminae act as the paths of least resistance through which tumors can spread. Knowledge of the intricate anatomy of this area and of the pathological behavior of the tumors is essential to understanding routes of tumor spread and to selecting an appropriate surgical approach for excision.

The skull base is divided into anterior, middle, and posterior regions according to the cranial fossae [53]. The crista galli, cribriform plate, orbital roof, and planum sphenoidale form the floor of the anterior cranial fossa. The squamous part of the temporal bone, the greater wing of the sphenoid bone, and the lower part of the parietal bone form the middle fossa of the skull base region. This region also includes tegmen and the petrous portion of the temporal bone. The posterior cranial fossa is formed by the posterior surface of the temporal bone near the cerebellopontine angle, the occipital bone, and the inferior clivus.

INDICATIONS

A review of the literature shows that over the past 30 years an increasing number of patients have undergone craniofacial resection and the definition of ''inoperability'' has undergone continuous revision. Tumors extending intracranially or into the infratemporal regions were previously considered ''unresectable'' [11,29,54,55]. With continued innovations in surgical techniques and the development of specialized skull base teams, lesions extending intracranially or to infratemporal regions may now be resected [55–57]. There remain some commonly accepted contraindications to skull base resections, based on the extent of the disease. These include bilateral optic nerve or chiasm involvement, massive brain involvement, internal carotid artery involvement when collateral circulation is absent [58], and medical illness of the patient. Debated contraindications include cavernous sinus invasion [59], internal carotid artery involvement, distant metastasis, and brain invasion. Most authors agree that the survival of patients with aggressive carcinomas is not improved with heroic resection of the cavernous sinus and carotid artery, in contrast to that of patients with low-grade tumors [58].

Factors influencing the decision of whether or not to perform radical skull base resection for malignancy include, the extent of disease, the predicted morbidity of the resection, the feasibility of complete en bloc resection, the natural history of the tumor, the need for postoperative radiation and its sequelae, and any comorbid conditions. Malignant tumors arising primarily in the frontoethmosphenoid complex or in the nasal cavity and/or maxillary antrum and orbiting with secondary extension to the skull base are amenable to resection by combined transcranial and transfacial (craniofacial) resection. Sinus cancers that approach the bony skull base should be resected by a combined facial and intracranial approach rather than risking inadvertent intracranial injury from a facial approach alone. Other malignancies commonly amenable to craniofacial resection include major and minor salivary gland tumors, advanced skin cancers, bone tumors, meningiomas, as well as neurogenic and neurovascular tumors.

PATHOLOGY

A review of reported series reveals that 80% of skull base resections were for malignant tumors. The most

common malignant histopathological entities reported were squamous cell carcinomas, adenocarcinomas and undifferentiated carcinomas of the paranasal sinuses and nasal cavity, esthesioneuroblastomas, squamous and basal cell carcinomas of the skin, melanomas, salivary gland tumors, sarcomas (leiomyosarcoma, fibrosarcoma, angiosarcoma, osteogenic sarcoma, chondrosarcoma, and malignant schwannoma), and chordomas. The commonest sites of origin of these tumors were the paranasal sinuses, nasal cavity, skin of the face and scalp, and cranial soft tissues. Tumor heterogeneity has been a feature noted in all reported series. The studies of McCaffrey et al. [48] and Levine et al. [47] showed a fairly high percentage of esthesioneuroblastomas, while the long-term follow-up report by Ketcham and Van Buren [31] showed only four esthesioneuroblastomas of 89 patients. Shah et al. [52] reported a high number of sarcomas and squamous cell carcinomas and a modest number of esthesioneuroblastomas. A large number of adenocarcinomas were reported by Bridger and Baldwin [35] (16 of 30 cases), Lund and Harrison [34] (25 of 92 cases), and Bebear et al. [38] (28 of 55 cases). Skin cancers predominated in reports from Brazil [41,51]. It must be emphasized that survival and disease control data from series consisting of mixed histologies are of limited value. The histology and natural history of the specific tumor type are the primary factors determining tumor control and survival.

PREOPERATIVE ASSESSMENT

Prior to surgery, a detailed history, physical examination, and laboratory evaluation directed toward assessment of cardiovascular and pulmonary comorbidity are critical and warrant assessment by cardiologists and anesthesiologists as necessary. All patients are seen by the head and neck surgeon, neurosurgeon, microsurgeon, and prosthodontist for planning the approach, extent of resection, and reconstruction. Preoperative counseling by specialist nurses and a psychosocial-vocational rehabilitation team is desirable, to provide a thorough understanding to the patient and his or her family.

The most critical element of the preoperative assessment of the patient with a skull base malignancy is the preoperative imaging that allows staging and treatment planning. The availability of CT and MRI has played a significant role in the development of skull base surgery; these techniques are complementary in the information they provide. CT scans with contrast in axial and coronal views with soft tissue and bone windows provide information about soft tissue extension and bone erosion by tumors. MRI scans provide superior discrimination between soft tissues, excellent assessment of early dura or brain involvement, and the possibility of sagittal sections. Software packages enabling interactive three-dimensional CT and MRI manipulation allow mock resections to be performed on the screen. Volumes, shapes, and types of tissue required to reconstruct the proposed defect may then be estimated [46]. Based on CT and MRI scans, other testing may be requested, including angiography, temporary balloon occlusion, and xenon blood flow studies, to clarify further the relationship of the tumor to the main vascular tree [60]. These tests permit an estimate of the impact of impairment of cerebral circulation in case of significant manipulation or sacrifice of an internal carotid artery [61]. Angiography followed by selective tumor embolization has been shown to improve intraoperative visualization, lessen the surgical blood loss, and decrease the length of surgery in selected vascular tumors of the skull base [62].

TABLE I. Key Technical Points

Adequate exposure
Minimal or no brain retraction
Slackening of the brain: continuous spinal drainage and/or mannitol-induced diuresis
Watertight dural seal
Reconstruction of skull base defect with pericranial, galeopericranial, or free flaps

SURGICAL TECHNIQUE

Technical details of anterior craniofacial surgery have been previously published [16,17,32,33,52,53], continue to evolve, and are adapted to the individual patient and lesion. The technical key points are listed in Table I. A spinal drain is placed preoperatively for CSF drainage to minimize brain retraction. Patients receive perioperative steroids and broad-spectrum antibiotics. The combination of vancomycin, metronidazole, and Ceftazidime is the preferred regimen in our experience. The intracranial portion of the procedure is performed first through a bicoronal scalp incision. In elevating the frontal scalp, a galeal-pericranial flap is created for the purpose of skull base reconstruction. A frontal craniotomy is performed. Alternatively, a subfrontal approach may be employed, incorporating a portion of the nasion with the frontal bone flap to facilitate access to the posterior aspect of the planum sphenoidale. If the dura is uninvolved, extradural dissection is performed with division of the olfactory roots at the cribriform plate and meticulous closure of the dural sleeves of the olfactory roots. If the dura is resected, the resulting defect is repaired with a free fascial or pericranial graft. Appropriate cuts are made in the cribriform plate, fovea ethmoidalis, planum sphenoidale, and orbital roof, depending on the extent of the tumor.

The transfacial exposure is obtained through a lateral rhinotomy or Weber-Ferguson incision with brow or subciliary extensions as needed. For ethmoidal lesions, resection incorporates the lateral nasal wall, septum, and ethmoid contents in continuity with the bony anterior skull base. Larger resections can incorporate the maxilla,

TABLE II. Technical Variations of Craniotomy

Single frontal burr hole [29,30]
Bifrontal craniotomy with multiple burr holes [16]
Parasagittal burr holes and Midas Rex saw [53]
Anterior subcranial approach [24,63]
Facial disassembly approach [25,27]
Frontal sinusotomy approach [64]
Nasofrontal swing approach [23]

TABLE III. Reconstruction Following Skull Base Surgery

Dura	Primary closure
	Free pericranium
	Fascia lata
	Temporalis fascia
Craniectomy	No bony reconstruction
	Autologous iliac crest or rib
	Freeze-dried iliac crest homograft
	Split calvarium
	Alloplastic material
Soft tissue	
Nonvascularized tissue	Split-thickness graft
	Fascia lata
	Pericranium
	Fat
	Temporalis fascia
Pedicled flaps	Pericranial flap
	Galeal-pericranial flap
	Temporalis myofascial flap
	Trapezius myocutaneous flap
	Scalp flap
Free microvascular flaps	Rectus abdominis
	Latissimus dorsi
	Radial forearm
	Tensor fascia lata
	Omentum

orbit, infratemporal fossa, and other involved skull base structures. Every attempt is made to deliver the specimen in a monobloc fashion. After appropriate reconstruction, the craniotomy and facial incisions are closed. Every attempt should be made to reconstruct the medial canthal ligament on the side of the medial maxillectomy in patients with orbital preservation, to allow for alignment of the globes and prevent telecanthus. Lacrimal stents are placed in the nasolacrimal duct to prevent postoperative stenosis and epiphora. Technical variations of craniotomy are listed in Table II.

RECONSTRUCTION

The goals of reconstruction of skull base defects are to restore separation of the CSF space from the sinonasal tract, to fill any existing defect, and to maintain cosmesis and function. Reconstruction following skull base surgery may require replacement of three types of tissue: dura, bone, and soft tissue. The options of reconstruction are listed in Table III. Wherever a tear or a minor deficit is created in the dura, it is meticulously closed to ensure a watertight seal. In cases where the dura is resected, a patch repair is performed and a watertight closure of the dura is ensured. Reconstruction of the bony defect in the skull base following resection of a tumor is not usually necessary. Split calvarial bone grafts are readily available and are occasionally used to prevent the brain pulsations from being transmitted to the globe. Alloplastic materials carry a high risk of infection secondary to contamination from the nasal cavity and, hence, are not suitable. Judicious use of a prosthesis in an individual case may avert the need for complex bony reconstruction. A good soft tissue coverage of the skull base defect acts as a barrier to infection between the cranial cavity and the nasal cavity. In most circumstances, a pedicled pericranial flap or a pedicled galeal-pericranial flap is satisfactory. The pericranial flap is relatively thin and its blood supply somewhat tenuous. A galeal-pericranial flap is stronger and more vascular [37,65]. Elevation of the galeal-pericranial flap is somewhat tedious since its separation from the scalp during elevation of the scalp flap is through the subcutaneous plane. If the galeal-pericranial flap is felt to be unsatisfactory for coverage of a large defect, then a microvascular free flap should be used. Rectus abdominis is usually the flap of choice for reconstruction of skull base defects because of its reliability, bulk, and long pedicle [49,52,66]. Neligan et al. [67] compared the results of 90 skull base defect reconstructions using local, pedicled, and free flap techniques over a 10-year period. They reported an overall complication rate of 33.5% for the free flap group as compared to 75% for the pedicled flap group. Clayman et al. [49] reported on 39 patients who underwent craniofacial resection with free flap reconstruction at MD Anderson Cancer Center from 1988 to 1992 and showed an overall complication rate of 36% and just two cases with CSF leak.

Factors affecting the choice of reconstruction are enumerated in Table IV. Prosthetic reconstruction should be considered when observation of the resection site is important, such as in patients where there is high risk of recurrence with the possibility of successful surgical salvage. Patients requiring postoperative radiotherapy benefit from copious vascularized tissue of free tissue transfer reconstructions.

COMPLICATIONS

Complications after anterior skull base surgery (Table V) include wound infection, meningitis, CSF leak, subdural or intradural abscess, pneumocephalus, hematoma, delayed return of neurological function, and ocular complications. Osteomyelitis of the frontal bone flap may require removal of the affected bone. The routine use of lumbar drainage catheter and effective soft tissue separation of the cranial and nasal cavities has resulted in a lowered incidence of CSF leaks, which can be managed conservatively with lumbar drainage in most instances. Pneumocephalus results from air forced from the nasal

TABLE IV. Factors Affecting the Choice of Reconstruction

Natural history of the disease
Possibility of salvage surgery
Suitability of donor tissues
Risk of surgical or radiation complications

TABLE V. Local Complications Following Skull Base Surgery

Osteomyelitis of the frontal bone flap
Meningitis
CSF leak
Flap necrosis
Major wound infection
Subdural/epidural abscess
Intracranial hematoma
Hemorrhage
Internal carotid artery thrombosis
CVA
Seizure
Delayed return of neurological status
Pneumocephalus/hydrocephalus
Blindness
Epiphora
Diplopia
Pain
Enophthalmos

CSF, cerebrospinal fluid; CVA, cerebrovascular accident.

cavity to the CSF space and can cause altered neurological function and meningitis. Some patients may experience ''acute brain syndrome'' due to excessive retraction of the brain during surgery. Meticulous attention must be paid to alignment of the medial canthal ligament in patients in whom the eye is preserved, to avoid any sagging and subsequent diplopia. Systemic complications may involve the respiratory, cardiovascular, hematological, or endocrine systems.

An overview of major complications is shown in Table VI. Except for the series of Terz et al. [18,19] and Dias et al. [51], operative mortality has been consistently reported to be under 5% (Tables VI, VII) [13,14,24,42,48, 49]. A total of 37 postoperative deaths were identified in this review, and meningitis was the most common cause (Table VIII). In the early reports of craniofacial surgery, morbidity due to intracranial infection was a major problem [18,19,28]. However, in more current reports, the commonest intracranial complications were frontal bone osteomyelitis, major local sepsis, meningitis, extradural and subdural abscesses, CSF rhinorrhea, intracranial hematoma, pneumocephalus, ocular complications, and neurological impairment. In the updated series of Shah and colleagues [52], a total of 40 (35%) patients, including four postoperative deaths, had major complications associated with craniofacial surgery. The most common postoperative complications in their series included frontal bone flap osteomyelitis (n = 17), major local sepsis (n = 14), delayed return of neurological function (n = 11), and meningitis (n = 6), with a number of patients suffering more than one complication. Other authors report major complications ranging from 26% to 63% (Table VI). CSF leak rates range from 5% to 20% [18,19,36,38,40–43,51] and meningitis rates from 5% to 10% [19,31,36,38,41,52]. Symptomatic pneumocephalus may be treated by a closed drainage system [69], though simple aspiration of the air by percutaneous puncture together with increase of inspired oxygen tension to 100% might relieve the symptoms more effectively [50,70]. Previous radiotherapy may play a role in the increased rate of infectious complications [40]. The incidence of neurological complications, such as cerebrovascular accident and intracranial bleeding, has declined only slightly over the years [58]. The most common orbital complication is disruption of the lacrimal drainage system, but the most serious is loss of vision [39,40,71].

RESULTS, SURVIVAL, AND PROGNOSTIC FACTORS

A series of 115 consecutive patients treated at Memorial Sloan-Kettering Cancer Center undergoing craniofacial resection for malignant neoplasms involving the anterior skull base with a mean follow-up of 4.7 years has been reported [52] . The disease-specific survival in that series was 58% and 48% at 5 and 10 years, respectively, with a median survival of 4.7 years. The most common pathologies seen were sarcoma, squamous carcinoma, adenocarcinoma, and esthesioneuroblastoma. At the time of that report, 55 patients were alive and free of disease, 46 patients were dead of disease, 12 were alive with disease, and two had died of other causes. There were four postoperative deaths. Local control was obtained in 75 (65%) patients. Review of the literature reveals overall survival of 44% to 74% (Table VI).

Histopathological tumor type and grade are two factors with prognostic significance. Among all malignant tumors, esthesioneuroblastoma carried the best prognosis [38, 47,48,52]. All 14 patients with esthesioneuroblastomas were alive with only one local recurrence in the series of Shah et al. [52]. The incidence of recurrence was particularly high in the series of Levine et al. [47], with eight of the 24 patients developing tumor recurrences. Still, 5-year disease-free survival for esthesioneuroblastoma was 90% compared to other tumors (59%, $P = 0.028$).

Squamous cell carcinomas fared better than adenoid cystic carcinoma [43]. Of patients with squamous cell carcinoma, 63% were free of disease or had died of other causes compared to only 20% of patients with adenoid cystic carcinoma. Among patients who had a recurrence, the disease-free interval was the shortest for adenoid cystic carcinoma when compared with patients with squamous cell carcinoma and sarcoma (16 months vs. 25 and 27 months, respectively) [43]. Melanoma carried the

TABLE VI. Complications of Craniofacial Resection for Anterior Skull Base Tumors*

Reference	Year	Patients	Mortality (%)	Morbidity (%)	CSF leak	Meningitis	Osteomyelitis	Infection (%)	Hematoma	Epidural infection/abscess	Wound infection	Pneumocephalus
Terz et al. [18]	1980	38	15	26	3	—	—	—	—	—	—	—
Terz et al. [19]	1980	28	10.7	35	5	2	2	14	—	—	—	—
Ketcham and Van Buren [31]	1985	89	3	54	5	7	5	31	—	3	13	—
Lund and Harrison [34]	1988	92	4	—	3	—	2	4	2	2	—	—
Van Tuyl and Gussack [36]	1991	21	1	50	4	2	6	48	—	2	—	1
Bebear et al. [38]	1992	62	6	—	3	3	1	13	1	3	—	—
Richtsmeier et al. [39]	1992	32	1	—	—	0	2	—	—	1	4	—
Catalona et al. [40]	1994	73	—	63	10	4	7	37	—	11	5	4
Medina dos Santos et al. [41]	1994	81	—	—	8	8	—	—	2	—	—	—
Irish et al. [42]	1994	73	0	44	8	2	—	—	1	9	—	—
Janecka et al. [43]	1994	183	2	33	6	2	—	—	—	—	4	—
McCaffrey et al. [48]	1994	54	0	—	2	—	4	11	1	2	—	—
McCutcheon et al. [50]	1996	76	1	—	3	—	—	1	6	—	1	5
Dias et al. [51]	1997	57	10	51	5	6	—	59	1	1	17	1
Shah et al. [52]	1997	115	3.5	35	—	6	17	—	—	—	14	—

*Only major series (>20 patients) reporting complications in detail have been included. CSF, cerebrospinal fluid.

worst prognosis. However, the 40% long-term survival for nasal cavity melanoma reported by Shah et al. [52] is actually an improvement over historical data for all mucosal melanomas of the head and neck reported from the same institution [52,72]. This may be attributed to high dose per fraction adjuvant radiotherapy [72]. In all other series, there were no long-term survivors with melanomas [34,36,40,43–45,47,50]. Ketcham and Van Buren [31] reported better survival in patients with carcinoma (53%) than those with sarcoma (38%). Well-differentiated carcinomas show improved local control compared to poorly differentiated tumors [33,36,73].

The extent of resection was used as a prognostic factor by Shah et al. [52]. This is in direct relation to the local tumor extension and tumor burden. Limited resection was defined as that incorporating the lateral nasal wall, sinonasal contents, and anterior skull base. An extended resection usually incorporated the hard palate, orbit, dura, brain, or other site, with many of these patients requiring resection of multiple sites. There was a highly significant relationship ($P = 0.009$) in patients undergoing a limited resection having improved survival compared to those undergoing a more extensive procedure. Similarly, survival in the patients of Medina dos Santos et al. [41] requiring free flaps for skull base reconstruction was significantly reduced compared to that in patients undergoing primary closure for cutaneous defects.

A number of authors have reported that dural invasion is a poor predictor of survival [36,39,51,52,74]. Kraus et al. [75] noted long-term survival in 83% of patients with no dural involvement from ethmoid cancer and in 14% of patients with dural involvement undergoing craniofacial resection. Van Tuyl and Gussack [36] reported nearly identical results. Catalona et al. [40] found local control in 91% of patients without dural involvement and in 64% with dural (and, in half of the patients, brain) invasion. Clayman et al. [49] found no long-term survivors in a cohort of patients with transdural invasion undergoing skull base resection. Dias et al. [51] also noted a statistically significant ($P = 0.005$) survival difference in patients with dural invasion (38%) vs. patients with intact dura (75%). It is interesting to note that virtually all of these reports show no decrease in survival when comparing patients with dural invasion alone to those with dural and limited brain invasion.

The presence of orbital invasion had a significant impact on survival reported by most authors [34, 36,48,52]. In the series of Lund and Harrison [34], 76% of patients with orbital exenteration died. Similarly, in the series of Van Tuyl and Gussack [36], 72% of patients in whom

TABLE VII. Treatment Outcomes Reported in the Literature

Reference	Year	Patients	Malig-nant (%)	Primary (%)	Mortality (%)	Morbidity (%)	Median F/U	Survival	Comments
Terz et al. [18]	1980	38	100	36	15	26	—	—	Only skin and soft tissue tumors, includes temporal bone resections
Terz et al. [19]	1980	28	100	NS[a]	10.7	35	—	72% at 3 yr	Survival for SCC[b] of PNS[c]
Ketcham and Van Buren [31]	1985	89	100	24	3	54 (older report)	10 yr	44%	
Lund and Harrison [34]	1988	92	83	NS	NS	NS	NS	59% O.S.[d]	
Bridger and Baldwin [35]	1989	30	100	NS	3	NS	NS	63%	
Panje et al. [23]	1989	42	NS	NS	NS	<10%	NS	49%	
Van Tuyl and Gussack [36]	1991	21	100	86	5	50	41 mo	57%	
Bebear et al. [38]	1992	62	100	NS	6	NS	NS	Corrected 5-yr 80%	For adenocarcinoma
Richtsmeier et al. [39]	1992	32	81	NS	3	NS	30.5 mo	54%	
Raveh et al. [24]	1993	78	46	NS	0	NS	NS	79.5% DFS[e], 88.5% O.S.	57% DFS for malignant tumors
Catalona et al. [40]	1994	73	86	60	3	63	3 yr	NS	
Medina dos Santos et al. [41]	1994	81	72	64	NS	NS	NS	O.S. (primary) 82%, (salvage) 37%	
Irish et al. [42]	1994	73	74	30	0	44	38 mo	71% O.S., 53% DFS at 4 yr; mean O.S. 58.14 mo	Includes temporal bone resections
Janecka et al. [68]	1994	50	100	46	0	6	40 mo	74% O.S., 64% DFS	Only PNS tumors
Jackson and Webster [46]	1994	190	100	NS	1	NS	6.5	51%	Includes all sites
Janecka et al. [43]	1994	183	73	37	2.1	33	30 mo	O.S. 67%	Includes all sites
Levine et al. [47]	1994	45	100	NS	2.3	NS	NS	77% DFS at 5 yr	
McCaffrey et al. [48]	1994	54	100	NS	0	NS	35.5 mo	5 yr O.S. 49%, DFS 39%	
Clayman et al. [49]	1995	39	100	NS	0	36	NS	55% 5-yr disease-specific survival	Includes all sites
McCutcheon et al. [50]	1996	76	95	NS	1	36	34 mo	63% at 2 yr	
Dias et al. [51]	1997	57	100	19	10	51	NS	56% 5-yr disease-specific survival	Only skin cancers
Shah et al. [52]	1997	115	100	61	3.5	35	4.7 yr	58% 5 yr, 48% 10 yr DFS	

[a]Not specified.
[b]Squamous cell carcinoma.
[c]Paranasal sinus.
[d]Overall survival.
[e]Disease-free survival.

TABLE VIII. Cause of Death Following Anterior Skull Base Surgery

Complication	Patients
Intracranial sepsis (meningitis, meningoencephalitis) [18,19,35,38,40,51,52]	15
Subdural abscess [31]	3
Intraoperative hemorrhage [18,19]	2
Thrombosis of internal carotid artery [43]	1
Hemorrhage from vertebral artery [43]	1
Intracerebral hematoma [38]	1
Brain injury [18]	1
Cardiac cause [38,40,50,52]	4
Pulmonary embolism [18,19,34]	4
Mesenteric artery thrombosis [43]	1
Gastrointestinal hemorrhage and DIC[a] [52]	1
Mediastinitis [18]	1
Head injury due to fall [39]	1
Cardiorespiratory arrest due to displaced tracheostomy tube [36]	1

[a]DIC, diffuse intravascular clotting.

orbit could be preserved survived compared to 40% requiring orbital exenteration. The reduced survival in patients requiring orbital exenteration is a reflection of more advanced disease.

Histopathological margins must be interpreted with great care as it is not possible to adequately assess all margins of the specimen from this region of complex anatomy. Information on margins was reported in four series only [41,43,49,52]. The incidence of negative margins was reported in as high as 70% of patients [41,52]. In spite of this, no survival advantage was demonstrated with identical incidence of 35% local recurrence in both margin-negative and margin-positive groups. Clayman et al. [49], in contrast, showed that no patients with positive margins survived. In addition, perineural invasion and vascular invasion were not reported to be significant factors influencing survival [41]. Little correlation between the histopathological adequacy of margins on the major specimen and survival data was found, though evidence of disease in additional tissue removed subsequent to removal of the en bloc tumor specimen showed a distressing correlation [29]. Postoperative radiotherapy for improvement in local control is indicated for patients with positive margins and for those with high-grade tumor, large tumor volume, or extensive local invasion, in spite of negative margins [58]. In spite of an aggressive approach through craniofacial surgery, local recurrence remains a problem . The incidence of local recurrence varied from 52% to 80% [42,47,48,52]. Regional recurrence, however, is less of a problem. Distant metastases were seen in 25% of patients who failed treatment [42,52].

RECURRENT AND UNRESECTABLE TUMORS

In selected cases, reoperation is offered, depending on the histology and the extent of disease. The prognosis continues to deteriorate with every recurrence, and salvage may be possible only in tumors of low-grade histology, such as chondrosarcomas or esthesioneuroblastomas [47] and, to a certain extent, adenoid cystic carcinomas [76].

Unresectable but previously untreated tumors may be treated by radiosurgery [77] or a multidisciplinary treatment program of chemo/radiotherapy. Harrison et al. [78] reported their experience with 20 patients of advanced unresectable paranasal sinus/cavity complex and nasopharynx treated with concomitant chemotherapy and accelerated fractionation radiotherapy. At 2 years, local progression-free survival was 94%, distant metastases-free survival was 57%, and overall survival was 80%.

SUMMARY

Advances in combined transcranial and transfacial (craniofacial) approaches for malignant tumors involving the anterior skull base have demonstrated improved survival. The technique allows adequate assessment of the intracranial extent of the tumor through an appropriate craniotomy. Vital structures, such as the dura, brain, and blood vessels, can be protected or resected and reconstructed safely. An en bloc excision can be accomplished. Dural defects and/or tears are satisfactorily repaired under direct vision, ensuring a watertight closure. Finally, adequate closure of the soft tissue defect is obtained, thus segregating the cranial cavity from the potentially infected nasal cavity and the nasopharynx with a resultant decrease in morbidity. Operative mortality is low, although complication rates are high. The technique is safe and continues to be improved, to reduce morbidity. To evaluate the true impact of this surgical procedure on improvement in survival as well as quality of life, a multiinstitutional registry with uniform indications is indicated. With increasing experience and well-defined indications, improvement in survival (from 50% to 60%) and reduction in morbidity (from 30% to 40%) can be demonstrated through multiinstitutional cooperative efforts.

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